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Estimating Cloud Parameters for NEROS I

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ESTIMATING CLOUD PARAMETERS FOR NEROS I

by

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GOES infrared and visible imagery were combined with surface and upper-air meteorological observations to determine cloud amounts and cloud-top heights over the NEROS grid for the periods 1200, 1500, and 1800 EDT, on 3, 4, and 13 August 1979. Cloud amounts were determined for cumulus clouds alone and for all clouds. Cloud-top heights were determined specifically for cumulus clouds.

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SECTION 1

INTRODUCTION

The primary objective of this research project was to determine cloud parameters (spatial and and vertical extent) which would be used in modeling the production of ozone in the boundary layer during specified periods of the Northeast Regional Oxidant Study (NEROS). The study area was 38° to 45°N latitude, and 69° to 84°W longitude (Figure 1). The specific tasks performed for this research project to accomplish this objective, were as follows:

Fractional coverage of cumulus clouds, when these clouds alone existed, was determined in each of the 1/4° longitude by 1/6° latitude NEROS grid squares, using GOES satellite imagery and synoptic meteorological observations for the periods 1200, 1500, and 1800 EDT, on 3, 4, and 13 August 1979.

The average top height of cumulus clouds was determined across the NEROS grid using the GOES infrared imagery and available upper-air temperature profiles.

The fractional coverage of all clouds, other than cumulus or multilayer clouds which might include cumulus, was determined for the NEROS grid.

A secondary objective was to examine the period for which the so-called "cloud buster" experiments were performed to determine cloud parameters such as those discussed above, and to study those parameters relative to <u>in situ</u> measurements of vertical velocity made in cumulus clouds to determine if a functional relationship could be developed between

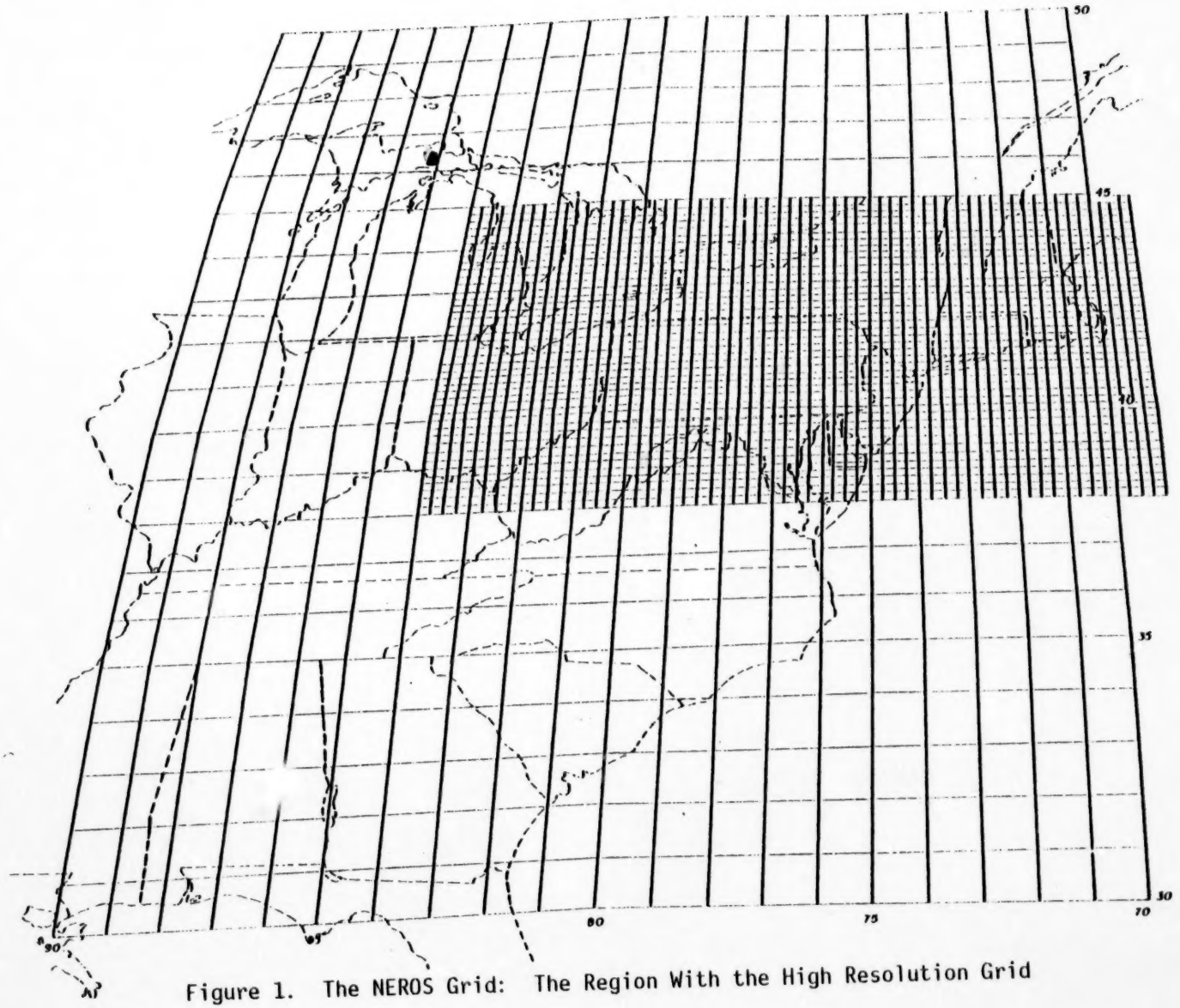

Figure 1. The NEROS Grid: The Region With the High Resolution Grid

the satellite cloud parameters and the cloud vertical velocities. This relationship could then be used to model the vertical ozone flux in cumulus clouds. The specific tasks are outlined below.

Available GOES infrared and visible imagery in or very near the periods of the "cloud buster" experiments (i.e., 1430 to 1530 EDT on 22 August 1979, and from 1400 to 1700 EDT on 28 August 1979) were used to determine the fractional coverage of cumulus clouds and the average height of the cumulus clouds within a fixed 20 km grid cell along transects performed by the aircraft used to collect in situ data.

In situ measurements made from the aircraft of the peak vertical velocity in the cumulus clouds, the average vertical velocity in the clouds, the ozone concentration in and around the clouds, and the upward- and downward-looking radiometer temperature in the vicinity of the clouds were determined along the transects from the data provided by EPA.

The vertical velocity data provided from the in situ measurements were compared with the cloud parameters obtained from the GOES data to determine if functional relationships exist.

Section 2 of this report describes procedures used to satisfy the tasks mentioned above. The section also describes the results of the analysis. Section 3 gives a discussion of the results and describes any recommended further study that may be necessary.

SECTION 2

TECHNICAL DISCUSSION

2.1 CLOUD PARAMETERS FOR THE NEROS GRID

2.2.1 Data Sources

The principal data utilized to meet the objectives of this research project were the GOES infrared and visible images obtained for 3, 4, and 13 August 1979. GOES visible images were available over the region of interest on the days in question at 1130, 1430, and 1730 EDT. The infrared data were available at 1200, 1500, and 1800 EDT. The GOES data were collected in hard copy image form and on magnetic tape by the Research Triangle Institute's (RTI) Satellite Receiving Station (Appendix A).

Synoptic weather data from the first-order surface-synoptic weather stations were also used in the region and for the time period of interest. These data were available at 1200, 1500, and 1800 EDT. Upper-air data were also utilized in this research project and were available from the National Weather Service Upper-Air Stations at 0200, 0800, and 1400 EDT. For the purpose of this research project, the 1400 EDT upper-air data was used extensively because they fell within the period of interest (1200 to 1800 EDT). These weather data were obtained from the National Climatic Center in Asheville, NC, and/or EPA.

2.1.2 Methodology

The steps employed to determine cloud amounts and cloud top heights over the NEROS grid are described below. It is understood that all analyses were developed in the region defined by the NEROS grid only. The NEROS grid covered the area 30° to 45°N and 69° to 84°W. The grid points were 1/4° longitude by 1/6° latitude.

1) The gray scale of the GOES infrared and visible images was enhanced (i.e., the gray scale was confined to a range of temperature and reflected radiation which gave the most useful information) using the data on magnetic tape and the facilities available at the RTI satellite receiving station (Appendix A) in order to facilitate interpretation of the satellite data.

2) The enhanced GOES visible and infrared (IR) images were photographically enlarged uniformly to further facilitate interpretation of the satellite data.

3) A NEROS grid overlay was developed on transparent Mylar for the GOES imagery.

4) The cloud amounts, the cloud types, and the cloud base heights from surface synoptic data were plotted on another transparent Mylar overlay.

5) An analysis delineating areas of clear skies, cumulus alone, and multiple cloud layers or clouds other than cumulus, were developed using the GOES visible and IR imagery and the plotted cloud data from the surface synoptic stations.

6) An analysis of cloud amounts in areas of cumulus alone and of multiple cloud layers or clouds other than cumulus was performed using the GOES visible and IR imagery and the surface synoptic cloud data.

7) An analysis of cumulus cloud-top temperature was performed using the GOES infrared imagery and calibration data available from the GOES User's Guide.

8) Cumulus cloud-top heights were derived using the cloud-top temperatures combined with the radiosonde data.

9) The cumulus (alone) cloud amounts (α_c), cloud amounts for conditions other than cumulus alone (α_a), and the cumulus top heights (H_c) were selected at each of the NEROS grid points, formatted, and placed on computer punchcards.

Cloud parameters from the surface synoptic data were plotted on transparent Mylar overlays using the GOES visible imagery to define geography. The plotted cloud data and the GOES visible and infrared images were then used to define regions of cumulus alone, clear skies, and multiple cloud layers. The visible images were used to interpolate in areas between synoptic weather stations. The infrared images were examined along with the visible imagery to determine if there was a change in cloud structure between synoptic stations which might indicate a change in cloud type. Similarly, an analysis of cloud amounts was performed using the GOES visible imagery, the analysis delineating areas of cumulus, clear skies, and multiple cloud layers, and the plotted cloud data. Once again, the visible imagery was used to interpolate in areas between the synoptic weather stations.

In order to obtain the cloud-top heights for the cumulus clouds, the gray scale for each of the GOES infrared images was calibrated with respect to temperatures using data available from the GOES User's Guide. For each GOES infrared image, patterns of shades of gray were analyzed on transparent Mylar overlays, and the patterns of gray scale were assigned temperatures using the calibrated gray scale. The satellite temperature in the area of cumulus clouds (T_s) and the temperature in the area of clear skies (T_a) in an area nearest the cumulus clouds were determined. The cumulus cloud-top temperature can be estimated using the following formula

$$T_c = T_a - \frac{1}{\alpha_c} (T_a - T_s) \qquad (1)$$

where α_c is the amount of cumulus clouds in tenths, and T_c is the cumulus cloud-top temperature.

The cumulus cloud-top height (H_c) was determined using the cumulus cloud-top temperature and the temperature profile obtained from the radiosonde stations nearest the cloud of interest. In all cases, the 1400 EDT radiosonde data were used for this purpose. The cumulus cloud-top temperature and cloud-top height were also estimated using the 1400 EDT radiosonde data and standard techniques (i.e., a parcel of air was lifted dry adiabatically to the lifting condensation level, then moist adiabatically to the level of free convection and the equilibrium level--the level of neutral buoyancy--and the cloud-top height was assumed to be the height of the equilibrium level). These values were compared with those values determined using the satellite data. If major discrepancies (differences $\geq$ 1000 m) were found, attempts were made to justify the differences. About 25 percent of the data for any given satellite analysis could not be verified using the calculations from the soundings. These discrepancies were generally due to the development of isolated large cumulus congestus and cumulonimbus clouds.

Afterwards, a transparent Mylar overlay of the NEROS grid was placed on the analysis of cloud amounts and the cloud-top height to determine those parameters at the grid points. These data were formatted and placed on computer punchcards, and the cards, with a statement of the format, delivered to EPA. The format for the cards is given in Table 1.

2.2 MODELING CLOUD VERTICAL VELOCITY

2.2.1 Preface

A second objective of this program was to examine the potential to develop a model which would predict the average maximum cloud vertical velocity using parameters obtained from satellite data: the cloud amount and cloud-top height. The model was to be used to parameterize the cloud vertical ozone flux for numerical models. Since this is the first attempt to develop such a relationship, and since the data resources are small, the result of this study may be considered as a guideline for more comprehensive studies in the future. The vertical velocity data were obtained by

TABLE 1. DATA CARD FORMAT FOR NEROS I ANALYSIS

b	D	D	T	T	C	C	R	R	F_C	F_C	H_T	H_T	H_T	F_A	F_A	b				
	C	C	R	R	F_C	F_C	H_T	H_T	H_T	F_A	F_A	b								
	C	C	R	R	F_C	F_C	H_T	H_T	H_T	F_A	F_A	b								
	C	C	R	R	F_C	F_C	H_T	H_T	H_T	F_A	F_A	b								
	C	C	R	R	F_C	F_C	H_T	H_T	H_T	F_A	F_A	b								
	C	C	R	R	F_C	F_C	H_T	H_T	H_T	F_A	F_A	b	b	b	b					

b = blank space

D = Day

T = Time (EDT)

R = Row

C = Column

F_C = Fractional coverage of cumulus clouds (01=10%)

H_T = Average top height of cumulus clouds (hundreds of feet)

F_A = Fractional coverage of all clouds (01=10%)

aircraft as a part of the so-called "cloud buster" experiment. The purpose of the cloud buster experiment was to collect data in order to study the vertical flux of ozone in clouds.

2.2.2 Data Sources

The principal data set that was utilized to determine the cloud amounts and cloud-top heights for the cloud buster experiments was the GOES infrared and visible imagery obtained for 22 and 28 August 1979. Since the collection of data made by the aircraft that was used in the cloud buster experiment took place from 1430 to 1530 EDT on 22 August and from 1400 to 1700 EDT on 28 August, the GOES visible and infrared images for 1430 and 1500 EDT, respectively, were used for this study. The GOES data were collected in hard copy image form and on magnetic tape by RTI.

Synoptic weather data from the first-order surface weather stations were also used in the region and for the time period of interest defined by the flight track (Figures 2 and 3). In all cases, the 1500 EDT weather data were used. The 1400 EDT upper-air data were also utilized to determine cloud-top heights. Cloud amounts and cloud-top heights were determined using the methodology discussed in Section 2.1.2 of this report and were determined in an area 20 km by 20 km centered along the flight track of the aircraft.

Various in situ measurements were made by an aircraft along the transects. For the purpose of this study, the aircraft data provided to RTI by EPA were used to determine the average maximum vertical velocity in cumulus clouds over a 20-km portion of the flight track (i.e., the peak vertical velocity was determined for each cloud in the 20-km portion of the flight track and an average was computed over all clouds in the cell) coincident with the same 20-km by 20-km region where cloud parameters were determined using satellite data. The upward- and downward-looking radiometer temperatures were also obtained to verify the existence of clouds.

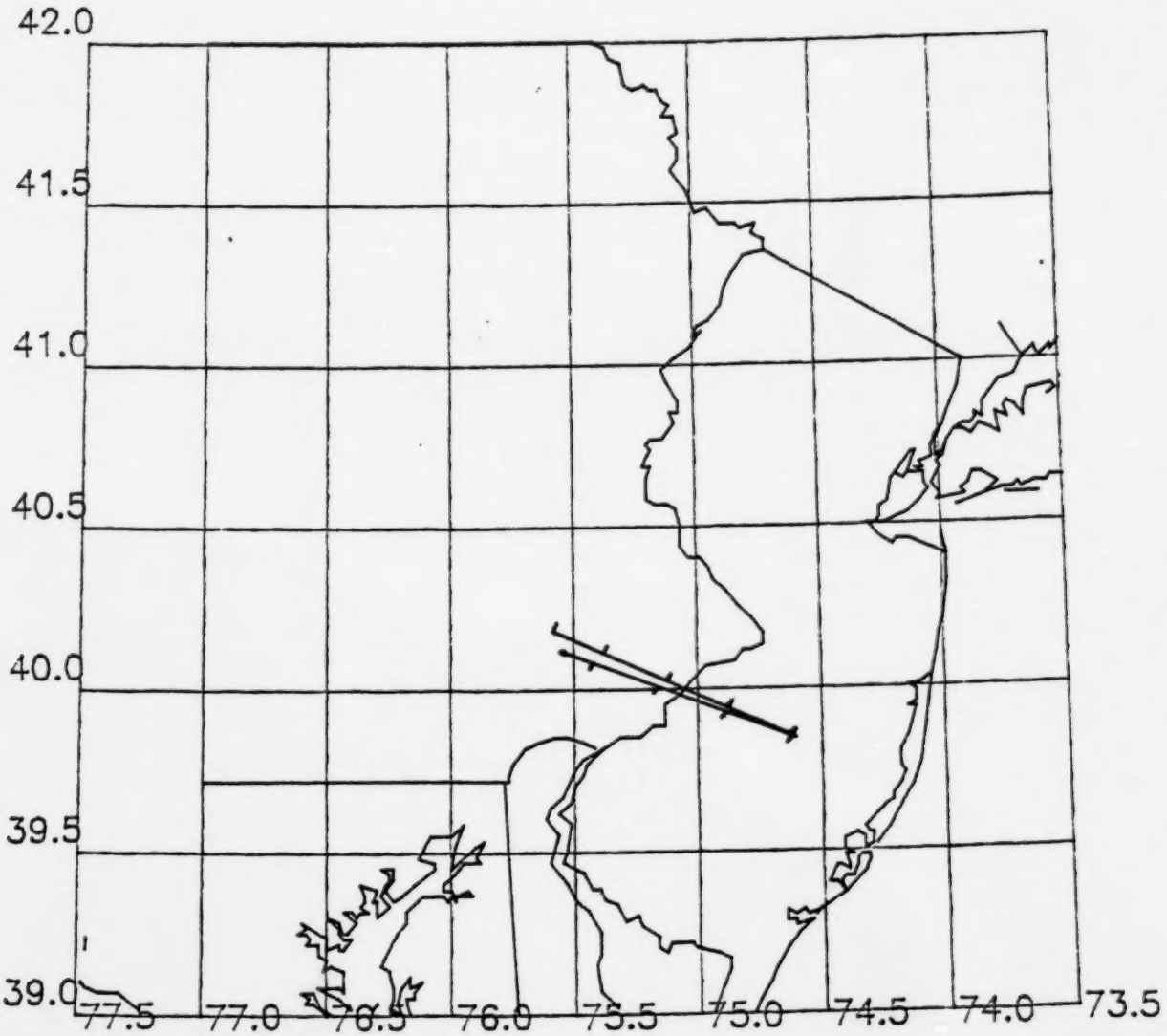

Figure 2. The two flight tracks for 22 August 1979 along which cloud parameters were determined and cloud vertical velocities were measured near the cloud base. Tick-marks indicate 20-km intervals.

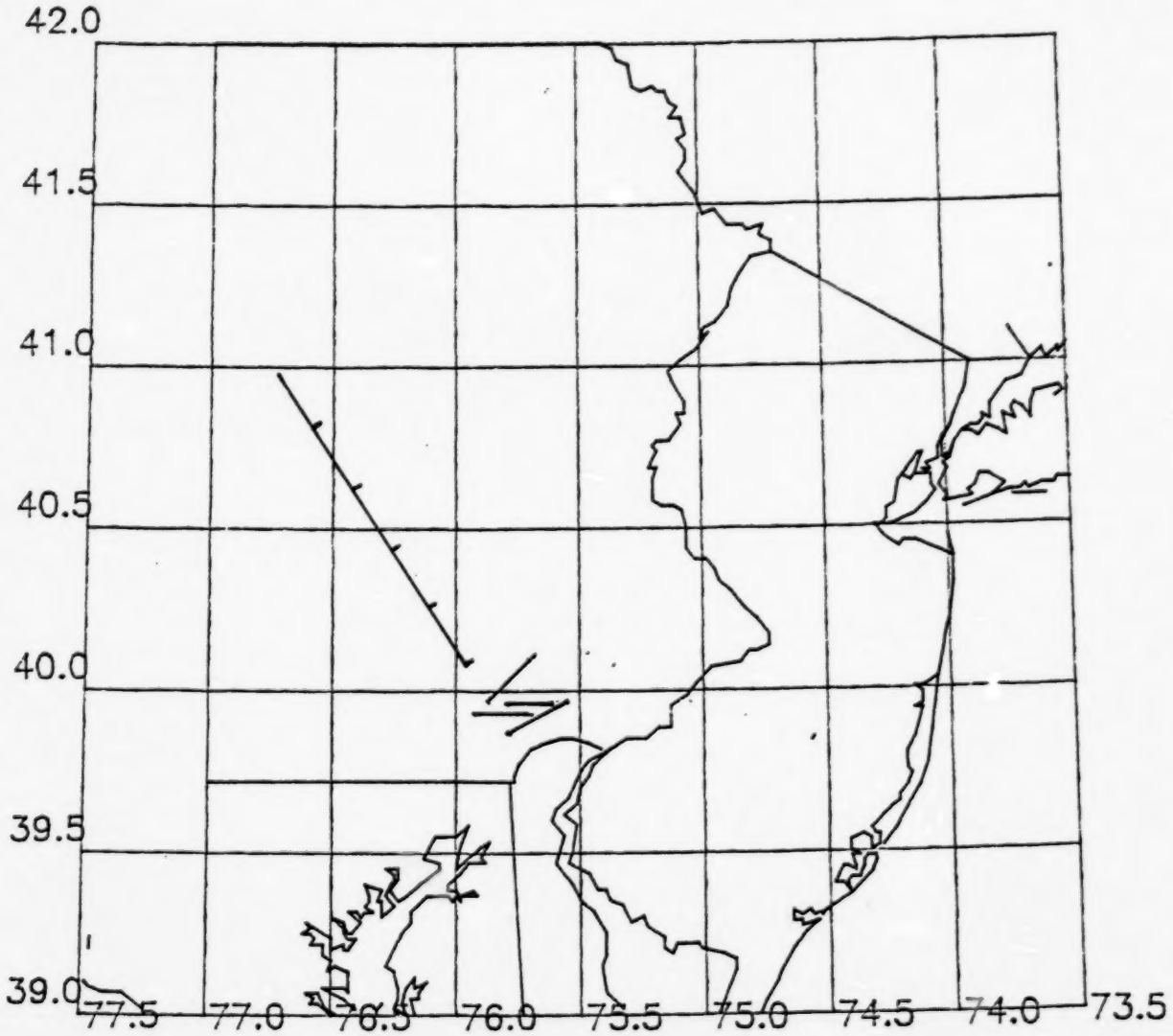

Figure 3. The five flight tracks for 28 August 1979 along which cloud parameters were determined and cloud vertical velocities were measured near the cloud base. Tick-marks indicate 20-km intervals.

The data reduction yielded nine independent data points from the various transects over the two days. The data points are given in Table 2. Data points 4 and 5 were obtained along a transect which bordered two distinct regions of cloud amounts and cloud top heights. For that reason, it was difficult to specify cloud amount or cloud-top height in these cases. The values given are associated with a cloud system with low cloud-top height and an approximate cloud amount of 0.3. The other cloud system had cloud-top heights on the order of 5,000 m and cloud amounts of approximately 0.6. Because of the problem of selection of proper cloud amounts and cloud-top heights in this case, it was decided that these two data points would be neglected in the following analysis. Discarding these two data points left only seven total data points for the analysis.

2.2.3 Modeling Results

The following models were used with the data in Table 2 to develop a relationship between the average maximum vertical velocity in the cloud and the cloud amount and top height derived from satellite data: a multiple linear regression model; polynomial models in which the average maximum cloud vertical velocity was related to the cloud amount; and polynomial models in which the average maximum cloud vertical velocity was related to the cloud-top height. The analysis indicated that increasing the degree of the polynomials to a value greater than three did not significantly improve the models. Table 3 yields statistics on the various models including the correlation coefficient and the root mean square difference (RMSD) between the estimated and the observed average maximum cloud vertical velocity. The coefficients of the models were determined through a standard regression algorithm developed for the Tektronix Model 4051 computer.

The data in Table 3 indicates that both the cloud-top height and the cloud amount are negatively correlated with the average maximum cloud vertical velocity; i.e., as the cloud amount increases and/or the cloud-top height increases, the average maximum cloud vertical velocity decreases. As the degree of the polynomial models increases for both the cloud amount and the cloud-top height, the magnitude of the correlation coefficient

TABLE 2. THE DATA SET USED TO DEVELOP THE MODEL

No.	w_c*	α_c**	H_T***	Time of Day for Data Point (EDT)
1	1.5	0.6	3700	1405
2	4.4	0.3	2550	1628
3	2.9	0.3	2550	1654
4	0.1	0.3	2550	1658
5	1.5	0.3	2550	1640
6	1.8	0.2	3600	1443
7	4.5	0.2	2700	1448
8	4.5	0.1	3600	1526
9	4.4	0.1	2700	1530

*w_c is the average maximum cloud vertical velocity in m s^{-1}.

**α_c is the cumulus cloud amount in tenths.

***H_T is the cumulus cloud-top height in meters.

TABLE 3. STATISTICAL ANALYSIS OF THE VARIOUS MODEL TYPES YIELDING ESTIMATES OF THE AVERAGE MAXIMUM CLOUD VERTICAL VELOCITY (w_e) AS A FUNCTION OF THE CUMULUS CLOUD-TOP HEIGHT (H_T) AND THE CUMULUS CLOUD AMOUNT (α_c), WHICH WERE DERIVED FROM SATELLITE DATA

Model	R*	RMSD**
$w_e = 7.8 - 4.4\ \alpha_c - 0.0011\ H_T$	-0.78	± 0.8
$w_e = 7.7 - 0.0014\ H_T$	-0.56	± 1.1
$w_e = 4.5 - 6.1\ \alpha_c$	-0.67	± 1.0
$w_e = 0.05\ H_T - 0.000009\ H_T^2 - 74.2$	-0.72	± 1.0
$w_e = 6.1 - 18.1\ \alpha_c + 17.4\ \alpha_c^2$	-0.67	± 1.0
$w_e = 131 - 0.15\ H_T + 0.00006\ H_T^2 - 0.000000007\ H_T^3$	-0.75	± 0.9
$w_e = 6.1 - 19\ \alpha_c + 20.8\ \alpha_c^2 - 3.3\ \alpha_c^3$	-0.75	± 0.8

*R is the correlation coefficient.

**RMSD is the root mean square difference between the observed and estimated average maximum cloud vertical velocity (m s^{-1}).

increased and the magnitude of the RMSD decreased. The statistical data in Table 3 suggest that the multiple linear regression model yielded the best relationship between the average maximum cloud vertical velocity and the cloud amount and the cloud-top height.

The specific form of the multiple linear regression model for the average maximum cloud vertical velocity derived using the data in Table 2 (with data points numbered 4 and 5 excluded) is

$$w_e = 7.8 - 4.4\ \alpha_c - 0.0011\ HT\ , \qquad (2)$$

where w_e is the estimated average maximum cloud vertical velocity, α_c is the cloud amount, and H_T is the cloud top height. Table 4 gives a comparison of the estimated and observed average maximum cloud vertical velocity utilizing the data in Table 2 and Equation (2) to generate the estimated values. Also given is the residual and the RMSD. On the average, there is a 24-percent error in the estimated average cloud vertical velocity, and the error decreases as the vertical velocity increases. However, it should be noted that these results are not statistically significant because of the limited data available for the development of the model. Improvement can be made in the data base available for model development if the NEROS I data base is combined with the NEROS II data base.

2.2.4 Recommendations

The fact that the cloud amount and cloud-top height were negatively correlated with the average maximum cloud vertical velocity was surprising and may be a result of the small data set. However, there is a potential that the results may be real. As clouds develop, both the horizontal and vertical dimensions increase (the cloud amount and the cloud-top height). Eventually, the cloud reaches a mature stage where the vertical velocity begins to decrease and approaches zero or begins to become negative if hydrometeors fall. Therefore, one can hypothesize that the maximum vertical velocity in isolated cumulus would be reached when the cloud is

TABLE 4. A COMPARISON OF THE OBSERVED (w_c) AND ESTIMATED (w_e) AVERAGE MAXIMUM VERTICAL VELOCITY (UNITS: m s^{-1})

w_c	w_e	Residual
1.5	1.2	0.3
4.4	3.8	0.6
2.9	3.8	-0.9
1.8	3.1	-1.3
4.5	4.1	0.4
4.5	3.6	0.9
4.4	4.5	-0.1

RMSD = ± 0.8 m s^{-1}

relatively small (i.e., in its development stage and not in its mature stage). However, such speculation can only be verified if the data set were to be increased substantially. Some increase in the data set can be obtained if the NEROS II data were combined with the NEROS I data. Through the combination of data sets, a better definition of the relationships may be developed.

APPENDIX A

RTI'S SATELLITE RECEIVING STATION

In 1972, the Research Triangle Institute's Satellite Receiving Station (RTI/SRS) was established on the campus of RTI. The RTI/SRS utilizes the direct readout infrared data from the Automatic Picture Transmission (APT) mode of the NOAA and the TIROS-N satellites. It also receives via telephone transmission line half-hourly infrared and visible imagery from the GOES satellite. In the APT mode, the signal receiver consists of a manual track, dual-yagi antenna (Figure A1) and an EMR 807 VHRR receiver (Figure A2). The received APT signals are transmitted simultaneously to the EMR 810 Scanning Radiometer Data Manipulator (SRDM) (Figure A2) and stored for subsequent analysis on a modified four-track magnetic tape recorder. From the SRDM, the signal is transmitted directly to the EMR 816 laser facsimile device (Figure A2) which produces 8 x 10 hard copy images.

The heart of the RTI/SRS is the SRDM. The SRDM consists of four key elements: digital scan converter, gamma corrector, calibrator, and contour generator. These key elements provide for quantitative radiometer data, data buffering, scan line linearization, pseudo-scan-line generation, contour generation, adjustable nonlinear gamma correction (limited contrast enhancement), and digital/analog conversion. These provisions enable the user to buffer and manipulate the data spatially, temporally, and in amplitude to produce an isotherm-contoured video output at a corrected 1-to-1 aspect ratio that can selectively enhance and emphasize to a limited degree in low or high contrast such environmental features as terrain, physical oceanographic features, ground cover, clouds, storm fronts, etc.

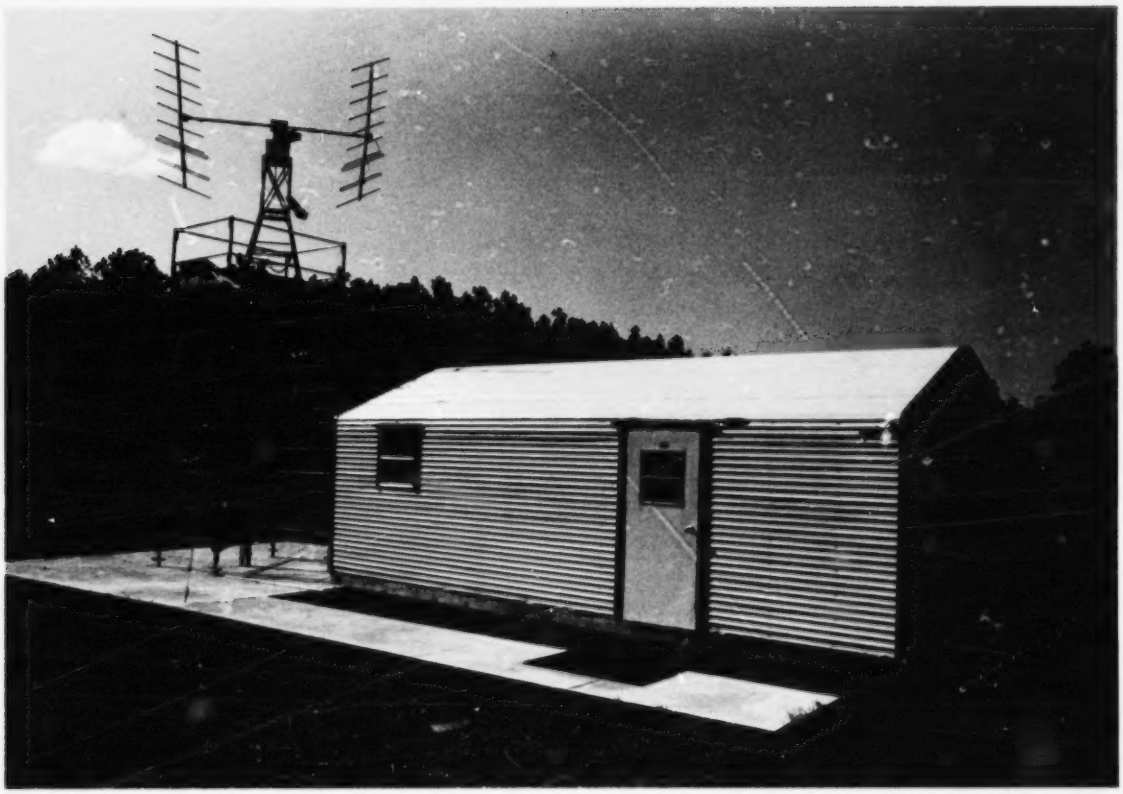

Figure A1. Outside View of Satellite Receiving Station

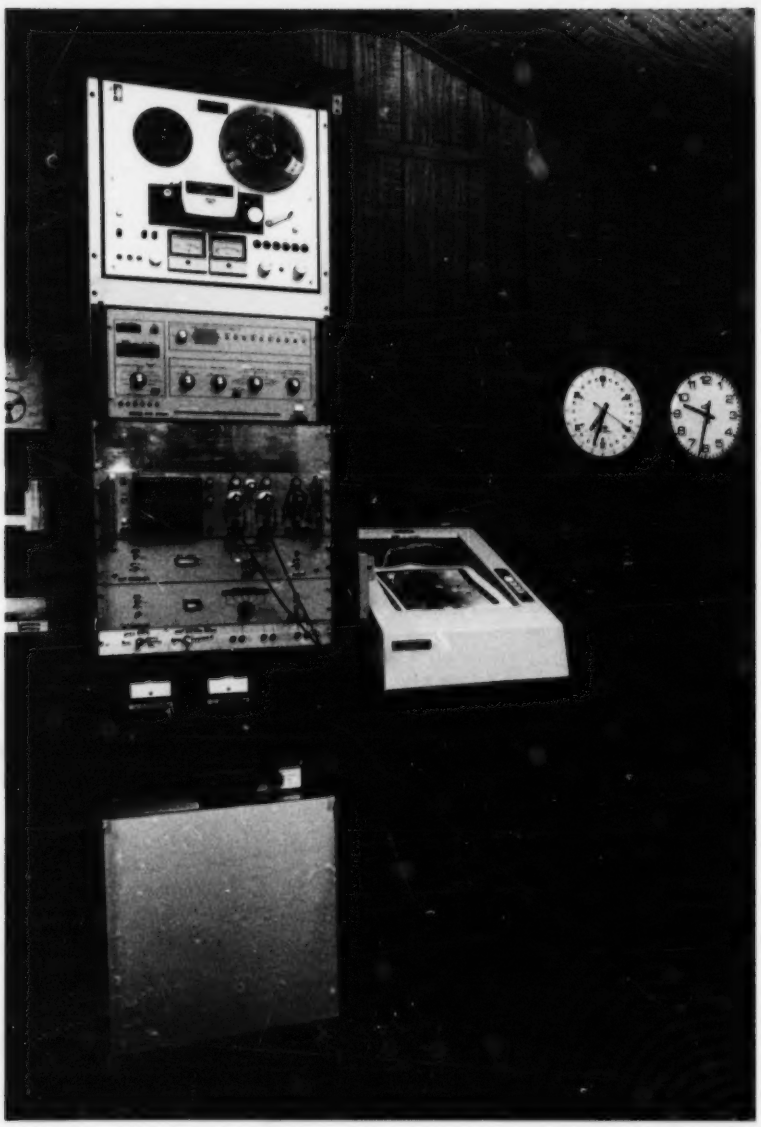

Figure A2. Control Panel for Satellite Receiving Station